

Quartic gauge couplings from $e^+e^- \rightarrow W^+W^-Z$

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Effective quartic gauge couplings on tree level appear in a strong interacting Higgs scenario, which could be relevant, e.g. if no standard model Higgs would be found¹. This scenario can be described in terms of an effective chiral Lagrangian valid for invariant energies $m_{W,Z} < \sqrt{s} < 4\pi v$, where the vacuum expectation value due to electroweak symmetry breaking is $v = (\sqrt{2}G_F)^{-1} \simeq 246$ GeV. It can be tested in a future linear collider². The Higgs potential is given as in the standard model and the Higgs fields can be described by a nonlinear realization of chiral symmetry³. The spontaneous symmetry breaking leads to masses of the gauge bosons. A systematic one-loop low energy expansion in the energy regime considered here leads to counter terms that require parameters that have to be determined by experiments. Because of the equivalence theorem the Higgs fields can be identified with the longitudinal components of the gauge bosons. Hence these counter terms can be identified with effective (anomalous) couplings between the gauge bosons. The generic quartic terms are¹

$$\mathcal{L}_4 = \alpha_4(\text{tr}V_\mu V_\nu)^2 \quad \mathcal{L}_5 = \alpha_5(\text{tr}V_\mu V^\mu)^2 \quad (1)$$

with $V_\mu \equiv -i\frac{g_W}{\sqrt{2}}(W_\mu^+\tau^+ + W_\mu^-\tau^-) - ig_Z Z_\mu \frac{\tau_3}{2}$. This interactions can be investigated through weak WW fusion⁴. The sensitivity at TESLA energies has been studied in Refs.^{2,5}. A comparison between WW fusion and WWZ or ZZZ production at LHC energies is given in Ref⁶. Recently WW fusion has been investigated for the e^-e^- option⁷. Induced quartic coupling via triple gauge coupling will not be considered here. Triple gauge couplings have been investigated previously².

As an example we presently consider the reaction $e^+e^- \rightarrow W^+W^-Z$. On tree level the elementary process is driven by 15 Feynman diagrams. Only one of the diagrams contains the quartic coupling and has to be extracted from the other interfering terms. Furthermore only the part containing longitudinal gauge bosons is expected to give a sizable signal related to electroweak symmetry breaking. Since the gauge bosons are short living states they decay and off-shell effects have to be taken into account. These can be accommodated by considering 6 fermion final states on the parton level, which is possible using Whizard as an event generator⁸. Presently we consider on-shell gauge bosons only (narrow width approximation) and hadronize the final state using

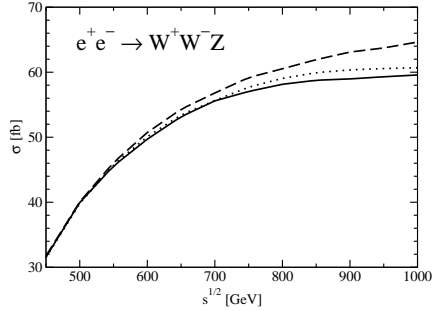


Figure 1: Energy dependence of partial cross section: standard model (solid line), $\alpha_4 = 0.1$, $\alpha_5 = 0$ (dotted), $\alpha_4 = 0$, $\alpha_5 = 0.1$ (dashed).

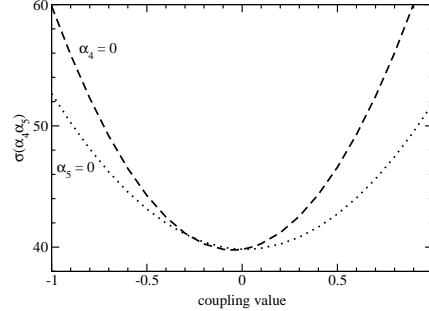


Figure 2: Dependence of cross section on α_4 and α_5 at $\sqrt{s} = 500$ GeV. Standard model value for $\alpha_4 = \alpha_5 = 0$ other $\alpha_4 = 0.1$, $\alpha_5 = 0$ (dotted), $\alpha_4 = 0$, $\alpha_5 = 0.1$ (dashed).

PYTHIA⁹. This restriction, however, will be relaxed as the investigation goes on. The partial cross section for the (no-Higgs) standard model result is shown as a solid line in Fig. 1. The other lines include the contributions from $\alpha_4 = 0.1$ and $\alpha_5 = 0.1$. The total cross section at 500 GeV as a function of α_4 or α_5 is shown in Fig. 2.

The three-boson state WWZ is characterized by three four-momenta and the spins. In general three momenta lead to 12 kinematical variables that are reduced by 4 through energy momentum conservation, by 3 because of the on-shell condition mentioned before, and by 2 due to rotational invariance. Hence in total three independent kinematical variables are left. We choose two invariant masses of the Dalitz plot, M_{WZ}^2 , M_{WW}^2 and the angle θ between the beam axis and the direction of the Z -boson. Spin leads to additional degrees of freedom, and we may differ between longitudinal and transverse polarization of the bosonic spins. Presently, we do not analyze the spins of the bosons.

The three independent kinematical variables lead to a three dimensional histogram. If the angle θ is not measured the resulting two dimensional histogram leads a Dalitz plot. We investigate the differences on the histograms as a function of α_4 and α_5 . The observables are discretized into bins and χ^2 is given by

$$\chi^2 = \sum_{i,j,k} \frac{N_{ijk}^{\text{exp}} - N_{ijk}^{\text{theo}}(\alpha_4, \alpha_5)}{\sigma_{ijk}^2} \quad (2)$$

where σ_{ijk} denotes the error, and i, j, k the sums over bins of M_{WZ}^2 , M_{WW}^2 , and θ . The theoretical values are achieved using Whizard that provides the

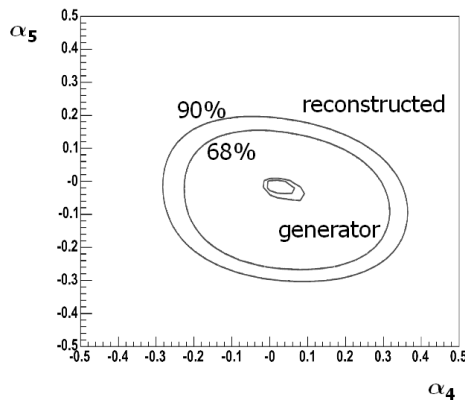


Figure 3: Expected sensitivity for ga_4 and α_5 at $\sqrt{s} = 500$ GeV for the process $e^+e^- \rightarrow W^+W^-Z$. The two inner lines represent the results on generator level (statistical error from 2 million events, 68% and 90% confidence). The outer two lines include detector efficiency and purity for a luminosity of 1000 fb^{-1} . To compare with $2 \rightarrow 2$ of the TDR the axis have to be scaled by $16\pi^2$.

partonic cross section and an interface to PYTHIA to do the hadronization. The detector efficiency is simulated using the fast simulation SIMDET¹⁰. We used a total number of 2 million events. In lack of experimental values we use as a reference an independent ensemble of 50,000 standard model events, that adds up to a luminosity of $1,000 \text{ fb}^{-1}$ for $\sqrt{s} = 500$ GeV. Since the effective Lagrangian is linear in α_4 , α_5 any observable is of second order in the parameters. Hence, we evaluate $N_{ijk}^{\text{theo}}(\alpha_4, \alpha_5)$ for a number of pairs (α_4, α_5) (15 to be specific) and fit

$$N_{ijk}^{\text{theo}}(\alpha_4, \alpha_5) = N_{ijk}^{\text{sm}} + N_{ijk}^{\text{A}}\alpha_4 + N_{ijk}^{\text{B}}\alpha_4^2 + N_{ijk}^{\text{C}}\alpha_5 + N_{ijk}^{\text{D}}\alpha_5^2 + N_{ijk}^{\text{E}}\alpha_4\alpha_5 \quad (3)$$

for each bin i, j, k by adjusting the 6 parameters $N_{ijk}^{\text{sm}}, \dots, N_{ijk}^{\text{E}}$ using Minuit. Finally we calculate χ^2 and determine $\Delta\alpha_4(\alpha_4, \alpha_5)$ and $\Delta\alpha_5(\alpha_4, \alpha_5)$ for the specific values $\chi^2 = 2.30$ (68.3% confidence) and $\chi^2 = 4.61$ (90% confidence). The results are depicted in Fig. 3.

To reconstruct the WWZ from the detector (SIMDET), we use the decay of $WWZ \rightarrow 6 \text{ jets}$. The branching ratio is about 32% which is about 16,000 events for the kinematics considered. The dominant background is due to $t\bar{t} \rightarrow b\bar{b}WW \rightarrow 6 \text{ jets}$ which adds up to 220,000 events. Events selection is done in the following way. We enforce 6 jets with missing energy and momentum $E_{\text{mis}}^2 + p_{\perp, \text{mis}}^2 < (65 \text{ GeV})^2$ and a minimum jet energy of $E_{\text{min}}^{\text{jet}} > 5 \text{ GeV}$. To reconstruct the WWZ we arrange the 6 jets into all possible 3 pairs, determine the candidate mass. We require $|m^{\text{cand}} - m^{\text{true}}| < 10 \text{ GeV}$ (where m^{true} is taken from the Particle Data Group), and take the best combination. To identify the dominant background we combine a candidate W from $t \rightarrow bW$ with 1 jets assume $|m_t^{\text{cand}} - m_t^{\text{true}}| < 15 \text{ GeV}$ and require an event consistent with the $t\bar{t}$

topology. This leads to an efficiency of about 60% and a purity of the signal of about 70%.

Conclusion and Perspectives

In the present analysis the potential of the process considered here has not yet been fully explored. So far we have considered correlations between two kinematical variables. Preliminary exploration shows that the sensitivity can be enhanced by about a factor of five, if the angle θ is considered in addition. Further improvements are possible, if longitudinal gauge bosons only are used in the analysis. Besides dominant 6-jet events, 4 jets $\ell^+\ell^-$ play an important role, because they provide rather clean signals. Furthermore ZZZ events have not been considered so far. The standard model cross section at 500 GeV is about 0.87 fb^{-1} , i.e. much smaller than the corresponding WWZ channel. However, the ZZZ channel is also sensitive to other anomalous couplings than the ones considered here. The narrow width approximation can be relaxed by using the full potential of Whizard that enables us to treat 6 fermion final states. From Fig. 1 is it clear that sensitivity to the anomalous couplings should be larger at higher energies, which is the next step in the analysis.

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